Renewable and Sustainable Energy Reviews 16 (2012) 4298–4302

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A review on renewable energy conceptual perspectives in North Africa using a polynomial optimization scheme

K. Boubaker

ESSTT/63 Rue Sidi Jabeur 5100, Mahdia, Tunisia

ARTICLE INFO

Article history:
Received 16 August 2011
Accepted 18 February 2012
Available online 14 May 2012

Keywords:
Renewable energy
Solar energy
Wind energy
Geothermal energy
North Africa
Data Envelopment Analysis (DEA)
European Union

ABSTRACT

In this review, general features of the renewable energy sources in the North African upper zone have been studied. The primal renewable sources of energy have been identified in Algeria, Morocco and Tunisia. Taking into account concordances and divergences of the different actors in the region, a polynomial optimization scheme has been performed in order to predict future potentials and perspectives.

Contents

1. Introduction

Renewable energy has become a priority for both governments of UMA member countries: Morocco, Algeria and Tunisia [1–11]. Like many other countries, they have pronounced renewable energy targets, representing an important part of their energy. In North Africa zone, renewable energies, more so than fossil fuels, represent a wide panoply of energy resources as biogenic, hydrothermal, geothermal, marine, wind, and solar, involving several processes like combustion, thermal, mechanical, chemical, photovoltaic protocols [3–7].

Indeed, national targets in this matter are not the same, due to historical and geographical differences. Nevertheless, the shared Mediterranean strategic location makes pressure toward common strategies and uniformed political ambitions.

The present article addresses this issue by evaluating the actual situation and previewing future scenarios on the basis of quantifiable and identifiable ratios like conversion cost and transport loss ratios with special emphasis on investment decisions and overall system costs up to 2025.

The model, based on Data Envelopment Analysis (DEA), minimizes dispatch and investment costs and simulates the impact of the renewable energy targets on the conventional generation system.

2. A panoramic overview

Tunisia is one of the windiest countries among the on the Mediterranean countries, with the central and southern parts of the country being frequently exposed to strong winds. Actually,

E-mail address: mmbb11112000@yahoo.fr

1364-0321/$ – see front matter
http://dx.doi.org/10.1016/j.rser.2012.02.077

wind farms with a total capacity of 2000 MW are inserted within the local electric network. The earliest wind farm in Tunisia, a was launched in 2000 in Sidi Daoud (Nord-East) with a nominal capacity of 10.56 MW, as stared by Abderrazzaq [1] and Ben Amar et al. [2]. One year before, the "Tunisian Solar Plan" have been started along with some other renewable energy projects including solar water heating and biomass development. According to (ANME) and Tunisian agency for renewable energies (ANER) previsions, projects in CSP and PV plants will only add up to a total capacity of 120 MW until 2016 while wind capacity is expected to yield about 330 MW in the same period [3].

Nevertheless, according to Kerkeni et al. [4], Mouldi [5] and Khemiri and Hassairi [6], Tunisia does not seem to take concrete measures to move towards further liberalisation and to open the renewable energy sectors to competition, despite showing an interest in the DESERTEC concept, established by the Club of Rome and TREC. This concept consists of bringing technology and deserts into service for energy, water and climate security.

On another hand, as the use of hot water in Tunisia is set to grow in both the domestic and tertiary sectors towards 2015, the potential volume of solar water-heaters is estimated at 1.5×10^6 m^3: 32,000 m^2 of captors have been installed so far. By 2010, the solar programme is aiming at a total of 1 million m^2 of solar captors, thus economizing on average 100,000 toe/year and avoiding the release of 3×10^5 tons of carbon dioxide into the atmosphere. In order to get industry fully involved in the development of solar water heaters, in 1996 Tunisia launched a 9-year project for the installation of 50,000 m^2 of water heaters [7].

Algeria is one of the most developed countries in the North Africa zone, its geographic location has several advantages for extensive use of solar and wind energy. Algeria is situated in the centre of North Africa between the 38 and 35° of latitude north and 8–12° longitude east, has an area exceeding 2.3×10^6 km^2 covered, at approximately 86%, by the Sahara [8].

Oil reserves in Algeria are estimated to 12.2 billion barrels, concentrated in two main basins: Hassi Messaoud and Berkine. Since domestic consumption level is not high, extracted surplus is exported mainly to the European Union [9,10].

The history of using solar energy in Algeria backs to 1954 with some French-installed units. The insulation time over the 95% of the territory is between 2000 and 3900 h/year with a mean value of 5 kWh/m^2 [9]. Many private installers companies are involved in this item.

On another hand, Algeria biomass presents 5.03 M Toe coming from forests and agricultural/urban wastes (365 kg per Algerian as urban wastes). This is associated to a plan of electricity production by modals of 2 MW with a peak of 6 MW from the discharge of Oued Smar in Algiers [10].

Concerning hydroelectricity potential and geothermic energy, they represent, in 2003, barely 1% and 5% of the total electricity production, respectively. In fact, overall flows, estimated to 65 billion m^3, benefit only to some efficiently exploited 50 (among more than 200) dams due to restrained rainfall days and high evaporation. Some 200 geothermal sources with temperatures exceeding 90 °C (i.e. Biskra and Hamam-El-Maskhoutin) are not fully exploited.

Nevertheless, as stated by Trieb et al. [11,12], Algeria's renewable electricity targets in the long run, by 2025, to reach 20% overall renewable coverage, in the proportions of 7:2:1 to CSP, wind and photovoltaic, respectively,

Despite its strategic position between the Mediterranean Sea and the Atlantic Ocean, Morocco is an energy deficient country. In the last decade, the country imported 95% of its primary energy demand. However, the country is characterized by an intensive solar radiation with an average of 5.3 kWh/m^2 under annual sunshine durations varying from 2700 h in the north to approximately 3500 h in the south. Other traditional energy sources like charcoal, biomass and wood are used extensively, especially in rural areas.

According to Zejli and Bennouna [13] and Barkia et al. [14], Morocco has more than 15% of the world reserves of oil shales whose exploitation has not been undertaken due to economic issues, while its electricity generation capacity in 2008, was approximately 5×10^3 MW, with contribution of thermal power stations, hydro plants, pumped hydro-storage stations and wind parks of about 65%, 25%, 8% and 2%, respectively. In the same period, the total electricity consumption was approximately 24 TWh.

In the matter of renewable energy, Morocco's goals focus on multiplying both wind and solar power plants. Wind installed capacity has been scheduled to increase from the current 253 MW in 2007 up to 2 GW until 2016. The majority of exploited plants are located alongside the country's Southern Atlantic coastline, where favourable wind conditions are comparable with European offshore sites. The Koudia-Al-Baida Farm is the largest wind farm in the continent, currently two others big wind farms are under construction in Tangier and Tarfaya. Concerning concentrating solar power (CSP), Escribano [15] and Benkhadra [16,17] detailed the 'Moroccan Solar Plan' which targets, until 2020, 2 GW CSP plants, in already managed sites, while a smaller program of grid-connected photovoltaic (PV) electricity is already initiated targeting a distributed PV capacity of 150 MW by 2015. Approximately, total renewable energy production is scheduled to be equally shared by solar, wind and hydro power [17].

3. Future insight

In the last two decades, wind and solar energy, among others, has received significant attention in North Africa as in other regions of the world. As hydropower faces stagnating expansion potential in this region due to geographical limitations, major efforts are developed toward wind and solar technologies. The first motivation is undoubtedly the increase of the global demand of the region (Fig. 1).

Nevertheless, and despite a favourable global solar radiation (Fig. 2), the currently installed solar plants in Algeria, Tunisia and Morocco, corresponds to a minor contribution (less than 1.5% of the overall installed electricity capacity of the region in 2009) [18].

The two most implemented efficient solar electricity facilities, namely concentrating solar thermal and Grid-connected photovoltaic (PV) plants as technically and economically discussed by Quaschning [19], do not exceed the capacity of approximately 50 MW in the whole region.

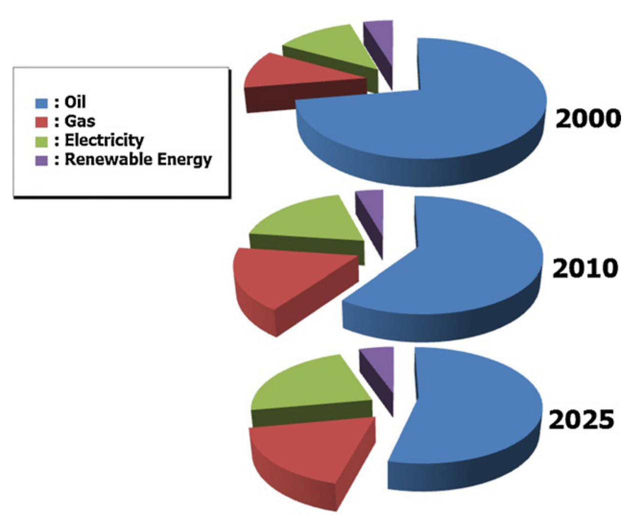

Fig. 1. Global demand of energy in the North Africa zone.

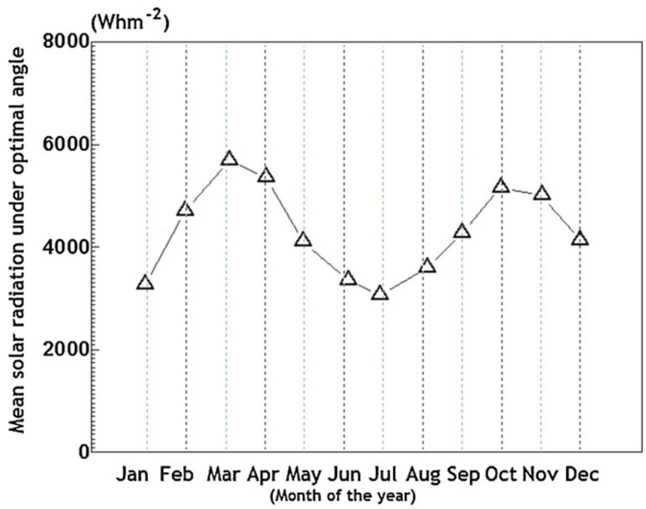

Fig. 2. North Africa zone global solar radiation.

At a first glance, the problem of the future resources and consumption cannot be discussed far from interaction with the immediate vicinity. Fig. 3 gives an overview of the actual and provisional (2025) energy exchange scheme within the Mediterranean Basin. It should be mentioned that the relationship between the European Union and Morocco, Algeria and Tunisia has been launched by Barcelona Declaration in 1995.

According to Piebalgs [20], Algeria supply is the master key in North-Africa-EU energy exchange scheme. In 2006, Algeria was the third gas importer for the EU. Fig. 3 shows also that 60% of the previsions would transit through the Algerian territory. Meanwhile, Morocco wind and solar energy potentials can significantly be increased. The estimated offshore wind potentials (22 EJ/year) including wind-intensive areas on ocean shelves and outside shipping lines and protected areas may compete with the Algerian supply provided that a combination of and appropriate policy framework, scientific knowledge, infrastructure and cooperation are established. The prospects of renewable energy in Tunisia show also a flourishing outcome, solar energy as an obvious example, has been assessed to be available in huge exploitable and transportable quantities throughout the country and all year round, particularly in the south.

On another hand, EU has relatively limited low-cost power production potentials from renewable energy sources, but it could import electricity produced from renewable energy sources in North-Africa (solar PV and CSP) and Eastern Europe (wind and biomass). This need depends partially on connections. Existing connections are quite reduced to the unique 400 kV line between Morocco and Spain. It represents the oldest transcontinental power

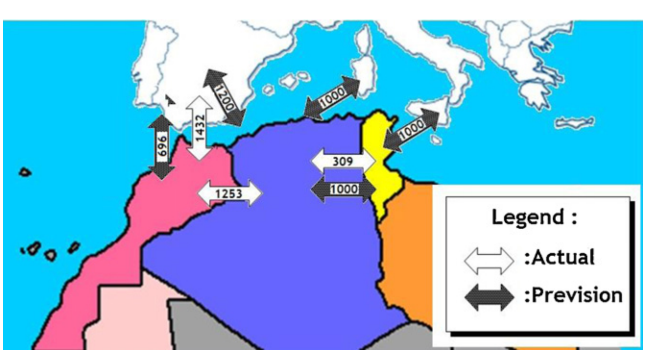

Fig. 3. Energy exchange scheme within the Mediterranean Basin (actual and prevision).

connection across the Mediterranean Sea, and is likely to be seconded by a DC undersea cable between Tunisia and Italy.

In this context of few transcontinental power gates, it is easier to bypass each local singularity by treating the North-Africa zone as a single unity, choosing mean pondered values for main measurable aggregates (production, evolution rates, costs, etc.) and individual values for intrinsic aggregates (distances, technological substitution rates, etc.)

4. Results and discussion

4.1. The optimizing protcol

In many countries today, there is a remarkable tendency for deregulation and restructuring of renewable energy-related industries [21–30]. In the actual case, analyses of present and projected performance in this field are based on an initial dataset is composed of N_0 observations ($N_0 = 7$) with six input variables $x_i|_{i=1\dots6}$ and two output variables y_1 and y_2.

Input dimensionless variables are chosen as:

x_1 : Total production of non-renewable energy
x_2 : Total production of renewable energy
x_3 : Fraction of non-renewable energy transited to EU
x_4 : Fraction of renewable energy transited to EU
x_5 : Unitary cost of non-renewable energy
x_6 : Unitary cost of non-renewable transport per unit distance

Output dimensionless variables are:

y_1 : Total relative savings for EU*.
y_2 : Total relative savings for North Africa zone*
(*compared to the situation of 100% non-renewable energy transactions)

For standardizing purposes, each variable t which varies inside the range $[t_{\min}, t_{\max}]$, is normalized using Eq. (1):

$$\hat{t} = \left[\frac{t - t_{\min}}{t_{\max} - t_{\min}} \right] \tag{1}$$

Consequently, the primal dataset is presented in Table 1.

4.2. Results

For a general N-input M-output problem, a polynomial expansion is proposed, for each variable $y_i\big|_{i=1,2}$ in order to reach the input combination of optimal observations:

$$y_i(x_1, x_2, x_3, x_4, x_5, x_6) = \prod_{j=1}^{6} \left(\frac{1}{2M} \sum_{q=1}^{M} \xi_{i,j,q} \times B_{4q}(\varpi_q x_j) \right) \tag{2}$$

where:

B_{4j}: 4j-order Boubaker polynomials [31–42]
ϖ_j: B_{4j} minimal positive roots
M: a prefixed integer
$\xi_{i,j,q}$: unknown pondering real coefficients.

The final solution is derived by introducing the expression (2) and calculating the coefficients $\xi^{sol.}_{i,j,q}\Big|_{\substack{i=1..2,\\ j=1..6,\\ q=1..M}}$ which minimize the

Table 1
Primal normalized dataset.

Observation	Inputs						Outputs	
	$\hat{x}_1$	$\hat{x}_2$	$\hat{x}_3$	$\hat{x}_4$	$\hat{x}_5$	$\hat{x}_6$	$\hat{y}_1$	$\hat{y}_2$
1	0.092	0.113	0.000	0.490	0.091	0.129	0.00	0.000
2	0.119	0.371	0.395	0.646	0.273	0.129	0.312	0.300
3	0.154	0.101	0.237	0.762	0.273	0.129	0.250	0.038
4	0.031	0.344	0.237	0.203	0.364	0.129	0.069	0.002
5	0.096	0.227	0.426	0.217	0.091	0.129	0.392	0.442
6	0.223	0.013	0.026	0.112	0.273	0.129	0.297	0.107
7	0.300	0.056	0.407	0.119	0.273	0.129	0.011	0.100

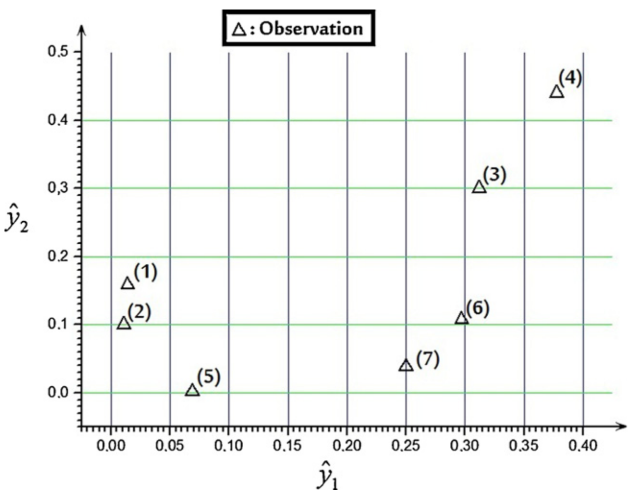

Fig. 4. Observations, presented in the $(\hat{y}_1, \hat{y}_2)$-plane.

functional determinant Ω:

$$\Omega = \left| \left(\hat{y}_{1,Obs.} - \prod_{j=1}^{6} \left(\frac{1}{2M} \sum_{q=1}^{M} \xi_{1,j,q} \times B_{4q}(\varpi_q x_j) \right) \right)^2 - \left(\hat{y}_{2,Obs.} - \prod_{j=1}^{6} \left(\frac{1}{2M} \sum_{q=1}^{M} \xi_{2,j,q} \times B_{4q}(\varpi_q x_j) \right) \right)^2 \right| \quad (3)$$

Figure 4 represents the output observations in the $(\hat{y}_1, \hat{y}_2)$-plane. Concordantly with precedent studies, it is possible to observe i.e. that two observations (2) and (5) are the most efficient ones as they are the closest to the origin (Fig. 4).These observations correspond to scenarios of maximum total relative savings for both sides. These scenarios don't differ significantly concerning total production of both non-renewable and renewable energy, but are in good agreement with actual potentialities concerning i.e. solar energy (Fig. 5).

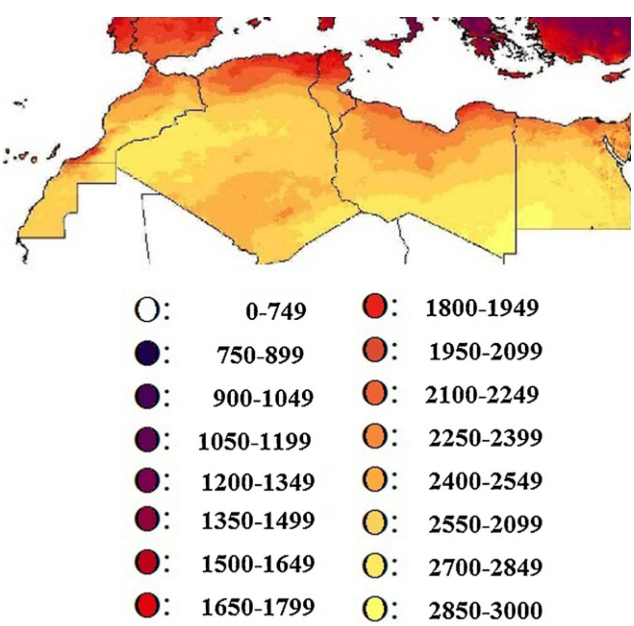

Fig. 5. Annual irradiance in the upper North Africa zone (2002, in kWhm^{-2}).

5. Conclusion

In this review we studied both actual and provisional scenarios for renewable energy in North Africa in relation with the EU. The mutual benefits of energy sources diversification has been proved through a consolidated optimization polynomial scheme. Different eventualities have been quantified and established in terms of total production of both renewable and non-renewable energy, unitary costs and related ratios at the Mediterranean basin level. The proposed model is being revised in order to take into account local interests and national priorities as well as short-term and long-term constraints.

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